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THEORETICAL AND EXPERIMENTAL STUDIES ON STEPPED SOLAR STILL

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ABSTRACT

In the present work, an attempt has been made to study the performance of a solar still. Many thermal models were developed by researchers to predict the performance of solar still. Thermal models developed by Dunkle and by Tsilingiris to predict the performance of the still is considered for the present study. A stepped solar still is fabricated for experimental study in the premises of SHIATS Allahabad (U.P.) India. It is observed that the daily productivity of more than 5 kg is obtained by still area of 1 m^2. It is further observed that the daily productivity predicted by Tsilingiris model is closer than the Dunkle model.

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1. INTRODUCTION

Water is precious to life. Often water sources are brackish containing harmful bacteria and therefore cannot be used for drinking. Distillation is the one of processes that can be used for water purification. Desalination refers to the process of removing salt and other minerals from water. Water is desalinated in order to convert salt water to fresh water which is suitable for human consumption. Various research works are being carried out to improve the performance of the still. The basin area of the still, free surface area of water, inlet temperature of water, wind velocity, solar radiation, depth are some of the factors that affect the productivity of the solar still. Moustafa et al (1979) carried out experimental studies on stepped solar still to improve the efficiency of the still by reducing the radiation losses from the basin. Suleiman (2007) studied the effect of water depth on productivity to show that a higher productivity was obtained for a low water depth. Velmurugan and Srithar (2007) used sponge cubes in the still to improve the productivity by 57.8% than the conventional still. Velmurugan et al. (2009) worked with an industrial effluent in a fin type single slope solar still and a stepped solar still separately. The maximum output was found in the fin type solar still. A new design of a stepped solar desalination system with a flashing chamber was experimentally investigated by El-Zahaby et al. (2010). In the present work a stepped

solar still with 8 number of steps were fabricated and tested in the premises of SHIATS Allahabad. Thermal models given by Dunkel and Tsilingiris were also validated.

2. THERMAL MODEL

The performance predication of solar still depends upon the accurate estimation of various heat and mass transfer coefficients between the components. Many researchers (Dunkle (1961), Chen et al (1984), Clark et al (1990), Kumar and Tiwari (1996), Zheng et al. (2001), Tsilingiri (2007)) developed many thermal models. Dunkle model is the most famous model to calculate the heat transfer coefficients and distillate output in solar still.

Dunkle model

Dunkle' s model is based on Nusselt –Rayleigh heat transfer analogy.

Distillate output rate per unit area $m_{th} = \frac{h_{cw} R_a}{c_p \ R_w} \frac{P_{o[P_w - P_g]}}{[(P_o - P_w)(P_o - P_g)]}$ (1)

Convective heat transfer coefficient

$$h_{cw} = 0.884\ [(T_w - T_g) + \frac{P_w - P_g}{268900 - P_w}\ (T_w + 273.15)\ ]^{1/3} \quad (2)$$

Tsilingiri model

This model is based on the Chiltone -Colburn analogy. The convective heat transfer coefficient is evaluated by using thermo-physical properties of saturated mixture (P. T. Tsilingiris, (2008))

Distillate output rate per unit area $m_{th} = \frac{h_{cw}}{\rho c_p \ Le^{2/3}} \left(\frac{P_O}{P_{LM}} \right) \left(\frac{M_w}{R} \right) \left(\frac{P_w}{T_w} - \frac{P_g}{T_g} \right)$ (3)

Logarithmic mean pressure (Pa) $P_{LM} = \frac{[(P_o - P_w) - (P_o - P_g)]}{ln\frac{(P_o - P_w)}{(P_o - P_g)}}$ (4)

Convective heat transfer coefficient

$$h_{cw} = 0.075\ \left(\frac{\rho . g . \beta}{\mu . \alpha}\right)^{1/3} [(T_w - T_g) + \frac{P_w - P_g}{268900 - P_w}\ (T_w + 273.15)\ ]^{1/3} \quad (5)$$

3. EXPERIMENTAL SET UP

Fig 1 shows a schematic diagram of the stepped solar still. The stepped solar still has the same construction and geometrical of the conventional solar still; expect the absorber plate is made of eight steps; which represents the absorber with an area of 1 m^2 .The steps are the dimensions of runway horizontal (10 cm) depth (6 cm). It is made up of Galvanized Iron sheet .The basin is coated with black painted. The still is kept in north south direction and condensing cover is inclined at an angle of 26^0. To measure the temperature, thermocouples are located in different points of the still. They record different temperature, such as glass cover and water temperature in the basin and ambient temperature. To measure the solar radiation solar meter is used and collected distillate is measured by a beaker. All experimental data are used to obtained the internal heat mass transfer coefficient for stepped slope still

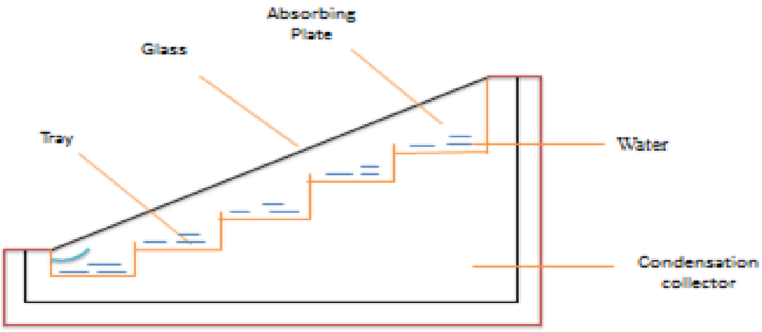

Figure .1 schematic diagrams of the stepped solar still

4. RESULTS AND DISCUSSION

The convective heat transfer coefficients and theoretical distillate are calculated by thermal models.

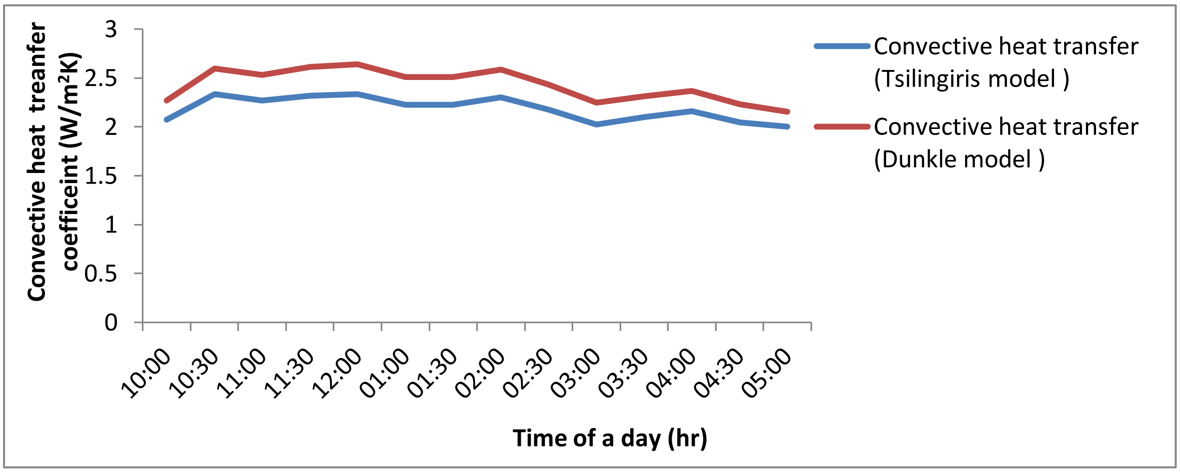

Figure 2 variation of convective heat transfer coefficient with time

Figure 2 shows the variation of convective heat transfer coefficient with time. The convective heat transfer coefficients calculated by Dunkle model is higher than Tsilingiris model. Figure 3 shows the variation of distillate output measured at 30 min interval. Distillate calculated by Dunkle model deviates more with experimental results compared to Tsilingiris model. A less than ten percent deviation is found in the results calculated by using Tsilingiris model than the experimental results. So performance prediction is more accurate by using Tsilingiris model than the Dunkle model.

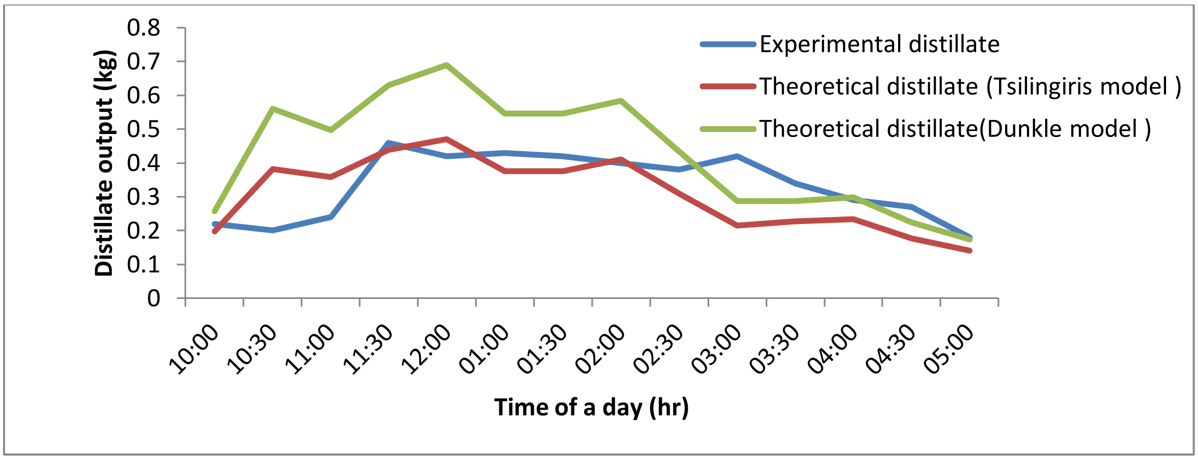

Figure 3 variation of distillate with time.

5. CONCLUSION

Theoretical and experimental studies were performed on stepped solar still. Thermal models developed by Dunkle and Tsilingiris were used to predict the performance of the still and the results were compare with experimental values. It is observed that the performance predicted by Tsilingiris model was closer to the experimental values than the Dunkle model. A deviation of less than 10% was observed between the productivity predicted by Tsilingiris model and the experimental results.

NOMENCLATURE

P_o reference pressure, 101325.16 Pa

P pressure, Pa

P_{LM} Logarithmic mean pressure, Pa

R universal gas constant, 8.31457 J $mol^{-1}K^{-1}$

R_a gas constant for dry air, 287 J $kg^{-1}K^{-1}$

R_w gas constant for water vapor, 461 J kg^{-1} K^{-1}

M_a molecular mass of air, 28.9645 Kg mol^{-1}

M_w molecular mass of water vapor, 18.016 Kg mol^{-1}

Le Lewis number

D diffusivity coefficient (mass diffusivity) of water in air, m^2 s^{-1}

k_v thermal conductivity ,W m^{-1} K^{-1}

h_{cw} convective heat transfer coefficient

GREEK SYMBOLS

ρ density ,Kg m^{-3}

μ dynamic viscosity ,Kg m^{-1} s^{-1}

ν kinematic viscosity, m^2s^{-1}

β volumetric expansion coefficient ,K^{-1}

α thermal diffusivity , m^{2} $^{-1}$

SUBSCRIPT

w water

g condensing cover

ew evaporative

cw convective

Thermo physical properties of saturated mixture (P.T. Tsilingiris (2007), P.T. Tsilingiris 2008, P.T. Tsilingiris 2010)).

1. $\rho_m = B_o + B_1 t + B_2 t^2 + B_3 t^3$

B_o= 1.299995662, B_1= -6.043625845 X 10 $^{-3}$, B_2= 4.696926602 X 10 $^{-5}$

B_3 = -5.760867827 X 10 $^{-7}$

2. $\mu_m = C_0+C_1 t + C_2 t^2+ C_3 t^3+ C_4 t^4$

C_0= 1.685731754 X 10 $^{-5}$, C_1 = 9.151853945 X10 $^{-8}$, C_2 = - 2.16276222 X10 $^{-9}$

C_3 = 3.413922553 X 10 $^{-11}$, C_4 = - 2.64437266 X 10 $^{-13}$

3. $\alpha_m = E_0 + E_1 t + E_2 t^2 + E_3 t^3$

E_0 = 1.881493006 x 10 $^{-5}$, E_1 = 8.027692454 x 10 $^{-8}$, E_2 = 1.496456991 x10 $^{-9}$

E_3 = - 2.112432387 x 10 $^{-11}$

4. $k_m = K_0+K_1 t+ K_2 t^2 + K_3 t^3$

K_0 =0.02416826077, K_1 =5.526004579 X10^{-5}, K_2 =4.631207189 X 10^{-7},

K_3 =9.489325324 X10^{-9}

5. $D_{w,a} = Q_O + Q_1 t + Q_2 t^2$

Q_0 =1.820034881 x 10 $^{-5}$, Q_1 = 1.324098731 x 10 $^{-7}$, Q_2 = 1.978458093 x10 $^{-10}$

6. $C_{pm} = F_0 +F_1 t +F_2 t^2+F_3 t^3+ F_4 t^4$

F_0 = 1.088022802, F_1 = - 0 .01057758092, F_2 = 4.769110559 x10 $^{-4}$,

F_3 = - 7.898561559x10^{-6}, F_4 = 5.122303796x10^{-8}

7. $Pr = N_O +N_1 t+N_2 t^2+N_3 t^3+N_4 t^4$

N_o = 0.7215798365, N_1 = - 3.703124976x10 $^{-4}$, N_2 =2.240599044x10^{-5}

N_3 = - 4.162785412x10 $^{-7}$, N_4 = 4.969218948x10 $^{-9}$

8. $P(t)= A_0 + A_1 t + A_2 t^2 + A_3 t^3+ A_4 t^4$

A_0 =1.131439334, A_1=3.750393331 x10^{-2}, A_2 =5.591559189x10^{-3}

A_3 = - 6.220459433 x10^{-5}, A_4 =1.10581611 x10^{-6}

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